

BELLCOMM, INC.

955 L'ENFANT PLAZA NORTH, S.W.

WASHINGTON, D. C. 20024

B70 06069

SUBJECT: Summary of Apollo 13 Launch
Vehicle Propellant Reserves -
Case 310

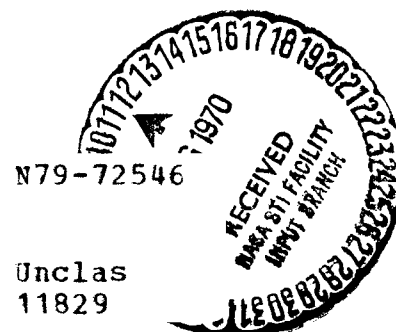
DATE: June 24, 1970

FROM: K. P. Klaasen

ABSTRACT

The S-IVB stage of the Apollo 13 Saturn V launch vehicle consumed a total of about 1700 pounds more propellant in reaching translunar injection (TLI) than the quantity predicted before the mission. This increase in propellant consumption resulted mainly from an early S-II stage center engine shutdown. The S-IVB stage performed slightly better than expected. The quantity of propellant remaining at TLI equalled the flight performance reserves required to cover the TLI burn plus enough usable propellant to provide from 1 to 5 seconds of additional burn time depending on the method used to compute usable propellant margin.

(NASA-CR-112973) SUMMARY OF APOLLO 13
LAUNCH VEHICLE PROPELLANT RESERVES
(Bellcomm, Inc.) 9 p



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MEMORANDUM FOR FILE

The Apollo 13 Saturn V launch vehicle (AS-508) satisfactorily boosted the spacecraft to a translunar injection (TLI). However, shutdown of the S-II stage center engine 132.4 seconds prior to the nominal shutdown time caused the S-IVB stage to consume about 1700 pounds more propellant than the pre-mission prediction.

Table 1 presents a summary of the predicted and actual quantities of S-IVB propellant remaining at various events during the launch. The predicted data was obtained from the AS-508 operational trajectory¹ and operational mass characteristics² for a March 12, 1970 launch with adjustments made for an April 11, 1970 launch³ and for subsequent increases of 34,000 pounds in the S-IC stage thrust, 0.18 seconds in the S-IC stage I_{sp} , and 457 pounds in the spacecraft weight. The actual Apollo 13 data was obtained from Flight Evaluation Working Group (FEWG) post-flight data.⁴ Significant differences between actual and predicted propellant quantities include:

1. about 100 pounds more propellant loaded,
2. 4477 pounds more propellant consumed during the first burn due mainly to the early S-II stage center engine shutdown,
3. about 450 pounds less propellant vented in earth parking orbit (EPO), due mainly to less propellant remaining in the tanks at the end of the first burn,
4. 2241 pounds less propellant consumed during the second burn due mainly to the lighter-weight vehicle in EPO, and
5. 1678 pounds less propellant remaining at TLI.

While the Apollo 13 spacecraft was in EPO, a real-time calculation was made at MSFC showing that there was sufficient S-IVB propellant remaining to execute the TLI burn. The propellant reserves were predicted to be equal to the required

flight performance reserve (FPR) for the TLI burn plus a margin of about 3 seconds of burn time. The FPR represents the quantity of propellant required to cover all negative 3σ propellant dispersions. The negative 3σ propellant dispersions used in the MSFC calculation were 1155 pounds of LOX and 531 pounds of LH_2 .*

A post TLI calculation by MSFC showed that the actual usable propellant reserves were equal to the FPR plus a margin of 3 to 4 seconds of burn time indicating the S-IVB performance during the TLI burn was slightly better than nominal.⁶

A calculation of the actual Apollo 13 S-IVB usable propellant margin at TLI based on FEWG data is presented in Table 2. The procedure used in determining the actual propellant margin is similar to that used in the launch vehicle dispersion analysis⁵ to make a pre-mission prediction of nominal propellant margin at TLI. The quantity of propellant in the lines and engine was obtained from the operational mass characteristics document,² and the quantity of propellant below the depletion sensors was listed in the operational trajectory.³ The calculation shows that 522 pounds of usable propellant margin (about 1 second of burn time) remained at TLI in addition to the FPR.

An alternate method of calculating usable margin is presented in Table 3. In this method, the FPR is subtracted from the available propellant before any propellant is labelled unusable as a result of mixture ratio considerations. Thus, quantities of fuel and oxidizer can no longer both be termed unusable as a result of the governing mixture ratio as could happen if the previous method is used. The total usable margin at TLI is, therefore, increased. The usable propellant margin in this case is 2324 pounds (about 5 seconds of burn time) in addition to the FPR.

*The required FPR is given in the launch vehicle dispersion analysis.⁵ The FPR of 1155 pounds of LOX and 531 pounds of LH_2 represents the negative 3σ dispersions in S-IVB stage propellant over both the first and second burns. In making a prediction of propellant margin at TLI given that the vehicle has already completed the burn into EPO, an FPR requirement covering only the second burn would apply. This FPR would be less than 1155 pounds of LOX and 531 pounds of LH_2 . Thus, the MSFC prediction was somewhat conservative.

In summary, calculations based on FEWG data show that on Apollo 13 the quantity of S-IVB propellant remaining at TLI equalled the FPR for the TLI burn plus enough usable margin to provide from 1 to 5 seconds of additional burn time. The real-time MSFC calculation showing propellant reserves equal to the FPR plus 3 to 4 seconds of burn time is consistent with these results.

K. P. Klaasen
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2013-KPK-slr

Attachments

BELLCOMM, INC.

REFERENCES

1. MSFC Memorandum, S&E-AERO-MFT-249-69, "Saturn V AS-508 Operational Trajectory for March 12, 1970 Launch," December 18, 1969.
2. MSFC Memorandum S&E-ASTN-SAE-70-4, "Saturn V/AS-508 Operational Mass Characteristics, Guidance Cutoff (Mission H-2) (March Launch)," January 12, 1970.
3. MSFC Memorandum S&E-AERO-MFT-4-70, "Saturn V AS-508 Operational Trajectory for April 11, 1970 Launch," January 19, 1970.
4. Telephone conversation with G. McKay, Jr., MSFC.
5. Boeing Co. Document D5-15553(I)-8, Volume I of II, "Saturn V AS-508 H-2 Mission Launch Vehicle Flight System Dispersion Analysis," January 22, 1970.
6. Telephone conversation with G. Wittenstein, MSFC.

EVENT	TOTAL LOX		TOTAL LH ₂		TOTAL PROPELLANT	
	Predicted	Actual	Predicted	Actual	Predicted	Actual
First Burn Start Command	191,532	191,523	43,500	43,596	235,032	235,119
First Burn	-55,666	-59,152	-11,208	-12,199	-66,874	-71,351
First Guidance Cutoff Signal (GCS1)	135,866	132,371	32,292	31,397	168,158	163,768
Thrust Decay and Engine Losses	-91	---	-32	---	-123	---
Parking Orbit Insertion	135,775	---	32,260	---	168,035	---
Orbit Losses	-176	-213*	-2,468	-2,083*	-2,644	-2,296*
Second Burn Start Command	135,599	132,158	29,792	29,314	165,391	161,472
TLI Burn	-130,570	-128,423	-27,479	-27,385	-158,049	-155,808
Second Guidance Cutoff Signal (GCS2)	5,029	3,735	2,313	1,929	7,342	5,664
Thrust Decay and Engine Losses	-105	-105**	-38	-38**	-143	-143**
TLI	4,924	3,630	2,275	1,891	7,199	5,521

*Includes thrust decay and engine losses.

**Assumed nominal.

All quantities given in pounds and include all liquid propellants in tanks, lines, and engine.

TABLE 1 - APOLLO 13 S-IVB PROPELLANT REMAINING

ITEM	TOTAL LOX	TOTAL LH ₂	TOTAL PROPELLANT
Total Liquid Propellant at TLI	3630	1891	5521
Propellant in Lines and Engine	-367	-48	-415
Tanked Propellant at TLI	3263	1843	5106
Propellant Below Depletion Sensors	-171	-712	-883
Available Propellant	3092	1131	4223
Unusable Propellant Due to 5:1 Mixture Ratio	-0	-513	-513
Usable Propellant at TLI	3092	618	3710
FPR (for TLI burn only - see footnote p. 2)	-1155	-531	-1686
Propellant Margin at TLI	1937	87	2024
Unusable Margin Due to 5:1 Mixture Ratio	-1502	-0	-1502
Usable Margin at TLI	435	87	522

All quantities given in pounds.

TABLE 2 - CALCULATION OF ACTUAL S-IVB
PROPELLANT MARGIN AT TLI

ITEM	TOTAL LOX	TOTAL LH ₂	TOTAL PROPELLANT
Total Liquid Propellant at TLI	3630	1891	5521
Propellant in Lines and Engine	-367	-48	-415
Tanked Propellant at TLI	3263	1843	5106
Propellant Below Depletion Sensors	-171	-712	-883
Available Propellant	3092	1131	4223
FPR (for TLI burn only - see footnote p. 2)	-1155	-531	-1686
Propellant Margin at TLI	1937	600	2537
Unusable Margin Due to 5:1 Mixture Ratio	-0	-213	-213
Usable Margin at TLI	1937	387	2324

All quantities given in pounds.

TABLE 3 - ALTERNATE CALCULATION OF ACTUAL
S-IVB PROPELLANT MARGIN AT TLI

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